

# Pneumatic contactless microfeeder design refinement through CFD simulation

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## Abstract

A new contactless pneumatic microfeeder based on distributed manipulation is proposed. By cooperation of dynamically programmable microactuators, the part to be conveyed floats over an air cushion and is moved to the desired location with the desired orientation. CFD simulations are used to test the validity of the proposed concept and refine the design of the microactuators.

**Keywords:** Microassembly, Microfeeder, Contactless, Distributed Manipulation, CFD Simulation

## 1. Introduction

Reconfigurable manufacturing has been emerging as a key technology for competitive business in today's environment where product life cycles are short and product turnover is high [1]. Reconfigurable assembly systems are a subset of this trend and as assembly provides the greatest value adding activity in manufacturing (80% of production costs of miniaturised systems occur in assembly [2]), this is a key area where reconfigurability can have a significant impact. Hence, flexibility is a fundamental feature for modern assembly systems.

The proposed paper reports on research at Nottingham University where the Precision Manufacturing Group work in the microassembly area aims at the development of a rapidly reconfigurable, plug & produce modular microassembly environment.

We make reference to a microassembly environment as, generally, researchers seem to focus only on grippers and actuators neglecting elements equally important such as feeders. Part feeding is the most restrictive entity in the quest for a satisfactory level of flexibility in microassembly systems. Flexibility in part feeding refers to the possibility to introduce new parts into the assembly system with minimal reconfiguration. Ultimate flexibility in feeding would require a device capable of accepting new parts without any or, at least, with a very short pause in the production.

This paper reports on the design refinement through CFD simulations of a pneumatic microfeeder that, through distributed manipulation, is capable of several functions such as translation, orientation, alignment and spatial filtering. The device is based on an array of microactuators each of which is made up of four nozzles. The nozzles are closed and opened by electrostatic forces giving the possibility to move objects in four different directions. Air is provided from the lower surface of the feeder so that the parts float over an air cushion and can be conveyed without being touched.

The microfeeder is designed not taking as reference a specific object. The only requirement is that the object is big enough to cover a few nozzles (each microactuator will have a size of about 300  $\mu\text{m}^2$ ). This feature will provide the so much needed

flexibility in modern microassembly systems.

## 2. Microfeeding – Contactless Manipulation

Feeders have the function of presenting parts that were previously randomly oriented to an assembly station at the same position, with the correct orientation and the correct speed. In microassembly, distributed manipulation (Figure 1) is a quite common approach for conveying microparts.

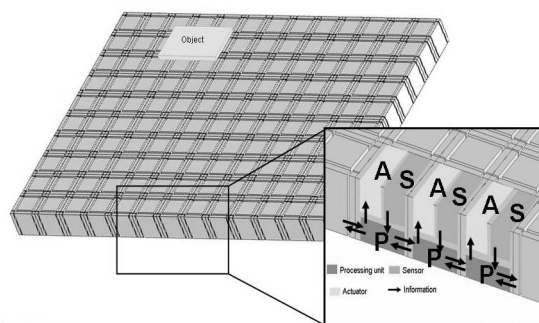


Fig. 1. Pneumatic contactless microfeeder

It is based on arrays of tiny actuators where each is able to provide a simple motion. Even though the motion imparted by a single element is within a small range, it is possible to move objects over relatively long distances through the cooperation of a large number of microactuators.

In microassembly, contactless manipulation is a feasible alternative because of the small size and lightweight of the objects to be moved.

Contactless manipulation is advantageous as [3]:

- Surface forces can be completely neglected
- It is suitable for handling fragile, freshly painted, sensitive micron-sized structured surfaces
- It allows the handling of non-rigid microparts
- There's no contamination of and from the end effector

## 3. Four directions microactuator

A pneumatic contactless microfeeder based on the principle of distributed manipulation is proposed.

The microfeeder consists of an array of micronozzles. Air is used for keeping the parts suspended. The parts are moved through the control of the micronozzles. As can be seen in Figure 2, a single microactuator is made up of four nozzles formed by a central electrode and four walls around it.



Fig. 2. Pneumatic microactuator

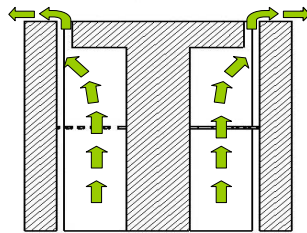


Fig. 3. Microactuator's cross section

The nozzles are opened or closed by electrostatic actuation. In the neutral position the four nozzles are all open: the airflow, coming from the bottom of the microactuator, is equally divided among the four nozzles because of the symmetry of the structure (Figure 3). The outcoming airflows are such that the resulting force field causes the micropart to hover above the microactuator (Figure 4). For moving the object, the central cursor is attracted towards one of the walls and the corresponding nozzle is closed. In Figure 5 the rightwards and leftwards jets compensate each other hence there's a net force that pushes the micropart downwards. A similar working principle was presented in [4]. The proposed design is advantageous because the single microactuator is more compact as it keeps the dimensions of the airflow channel constant. Moreover, movement in four orthogonal directions is achieved with a single microactuator whereas in [4] the same result is obtained combining four different microactuators capable of conveying objects in two directions only. This feature is of paramount importance as distributed manipulation becomes more effective if two conditions are satisfied: the microactuators have to be as small as possible, as their size directly affects the minimum size of the parts that can be moved, and the density of microactuators has to be high because this directly influences the position resolution that can be achieved. Hence, having a smaller individual microactuators improves the performance of the microfeeder.

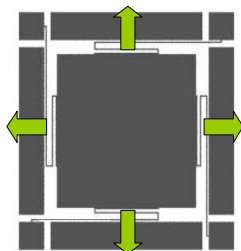


Fig. 4. Top view of the microactuator in neutral position

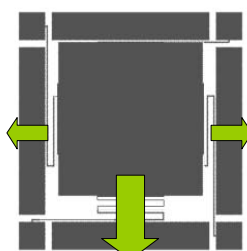


Fig. 5. Top view of the microactuator in active position

The microfeeder manufacturing sequence is based on IC-compatible fabrication process so that it is possible to obtain a high number of microactuators all the same time. The array is then mounted and electrically connected to a printed circuit board. This means that the electrodes are fixed at the base and bend slightly for closing the nozzles. For this reason, as can be seen in Figure 6, the lower part of the central electrode is connected with four springs to four "pillars" placed between the side electrodes. The springs increase the robustness of the structure and help the electrode to return to its central position. This task can be accomplished also through the control of the electric field that acts upon the cursor.

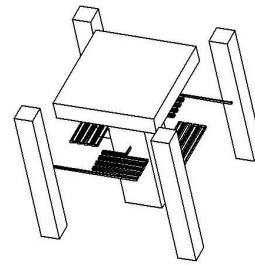


Fig. 6. View of the microactuator without the side walls

### 3.1. Microfeeding functionalities

The air jets coming out of the microactuators form a force field that can be globally controlled through the local control of the nozzles. As a result of this coordinated motion several functionalities, which are specific tasks of a feeding system, can be generated.

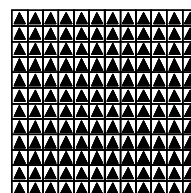


Fig. 7. Transport mode

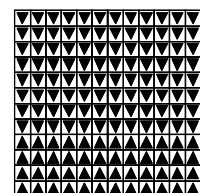


Fig. 8. Aligning mode

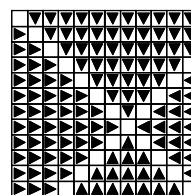


Fig. 9. Positioning mode

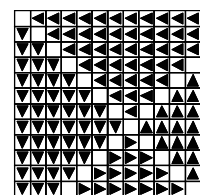


Fig. 10. Rotating mode

For transporting a part (Figure 7), all the air jets point in the same direction. If there's the need to align microparts (figure 8), the feeder's surface can be divided into two regions in which the relative force fields move the parts into two opposite directions. The parts align along the border of the two regions. Airflows can be arranged in a way such that the microparts are moved to any specific position (figure 9). The borders between different regions with different force fields act as spatial filters. It is also

possible to maintain the position and just change the orientation (figure 10) with four orthogonal force fields. As all the nozzles can be independently activated, the force field due to the air jets is dynamically controllable. Hence, several feeding functionalities can be obtained in cascade: a micropart placed on the feeder is moved to the desired position, its orientation is changed according to the particular needs and then it is moved to a different position which acts as a dead nest.

#### 4. Microsystems as integrated systems

The proposed microfeeder, as any other microsystem, entails integration of space, function and physics. The multiphysics feature is apparent considering that the individual “pixels” of the array behave like the armours of a capacitor and are therefore opened and closed by electrostatic actuation. The electrodes bend towards each other, being connected at their bases to a PCB, hence there is need to take into account the mechanical stability of the structure. Fluid-dynamics plays a major role in the behaviour of the device as air is used for conveying objects without contact.

At this stage, the focus is on the analysis of the airflow distribution rather than a detailed integration of all the aspects such as electrostatic actuation and mechanical deformation. Keeping this in mind, indications about the validity of the design is obtained by means of CFD (Computational Fluid Dynamics) simulations. CFD provides a tool for the analysis of the system and is a means to assess the effects of structural changes on the airflow distribution.

##### 4.1. CFD Simulation

Considering the symmetry of the microactuator in two perpendicular directions, it can be represented with a 2D model.

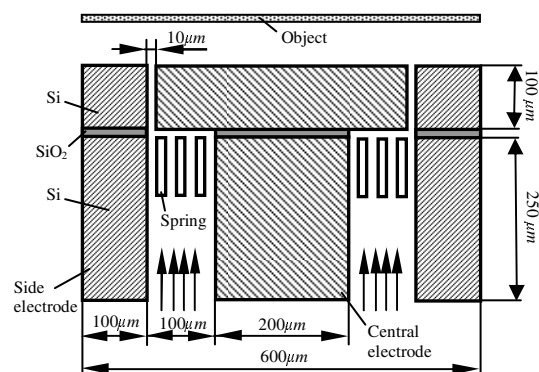


Fig. 11. 2D model of the pneumatic actuator

Figure 11 shows the geometrical description of the microactuator in neutral position, with the central electrode which is at the same distance from both the side electrodes. The simulations give an insight of the airflow direction and its interaction with the conveyed object. Two different situations are analysed: neutral and active position. For the latter it is assumed that the electrodes don't change their shape but the central electrode translates towards the side electrodes for closing the nozzle. This assumption is acceptable considering that the electrodes have to

move towards each other of a small quantity ( $5\text{ }\mu\text{m}$  each for the case in Figure 11) hence there will not be a significant distortion of the structure.

In the very first stages, simulations run with COMSOL confirmed that the airflow is distributed as expected and represented in Figure 3. The results of the simulation can be seen in Figure 12.

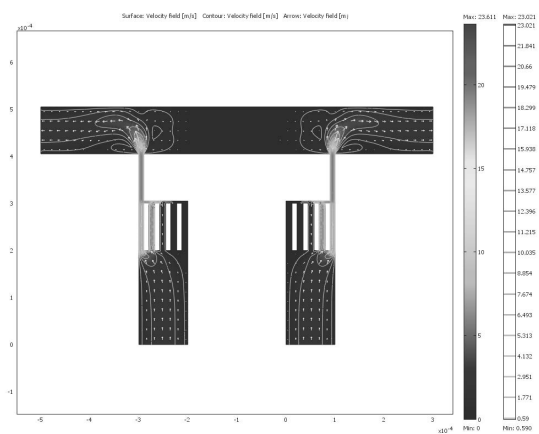


Fig. 12. Flow velocity, with inlet 14kPa and outlet 8kPa Modelled by FE Package COMSOL

At this point, three analysis packages, PHYSICA, ANSYS and COMSOL, were used in the simulation of this case to assess their suitability. The results obtained from the three packages were consistent. For the case represented in Figure 13, for example, the maximum airflow velocities of the microfeeder obtained by the packages ANSYS, PHYSICA and COMSOL are 21.0m/s, 22.3m/s and 23.0 m/s, respectively. Figure 13 shows the velocity profile of the airflow simulated with PHYSICA. The input air pressure in the inlet is 8kPa.

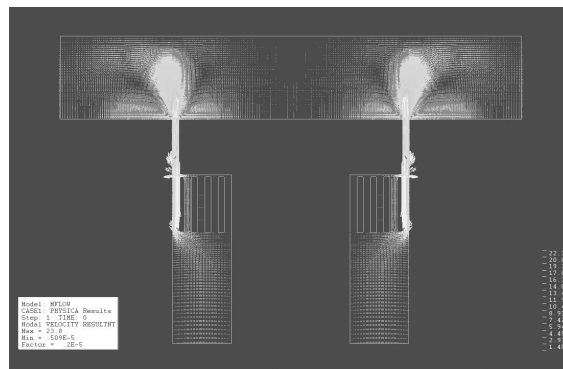


Fig. 13. Air velocity profile with the actuator in neutral position

The simulation in Figure 14 shows how, when the actuator is active (the central electrode is translated to the left so to close the left nozzle and make the right nozzle wider), the outgoing airflow is almost entirely vertical whereas, according to Figure 3, it should have a significant component directed to the right hand side. For this reason, the effects of changes in the relative height between the central and the side electrodes on the airflow direction were assessed. Simulations were run with the top surface of the central electrode at  $50\mu\text{m}$ ,  $100\mu\text{m}$  and  $150\mu\text{m}$  from the top surface of the side electrodes. In this way, the protruding side of the central electrode

guides and deflects the outcoming airflow.

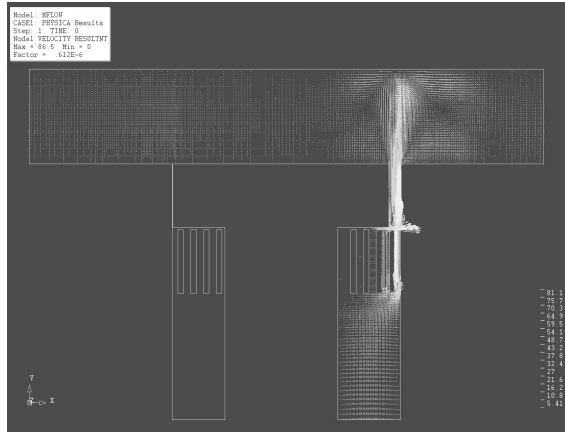


Fig. 14. Air velocity profile with the actuator in active position

The results were encouraging as, not only the deflection of the airflow, but also the speed, was increased. The maximum velocity of airflow increased from 22m/s in the same height position (Figure 13) to 41m/s when the distance is 50 $\mu$ m and reached to 60m/s in the case when the distance is 100 $\mu$ m. The most prominent change in the airflow direction (both in neutral and active position) is obtained in the case when the top surface of the central electrode is 120 $\mu$ m above the top surface of the side electrodes as shown in Figure 15.

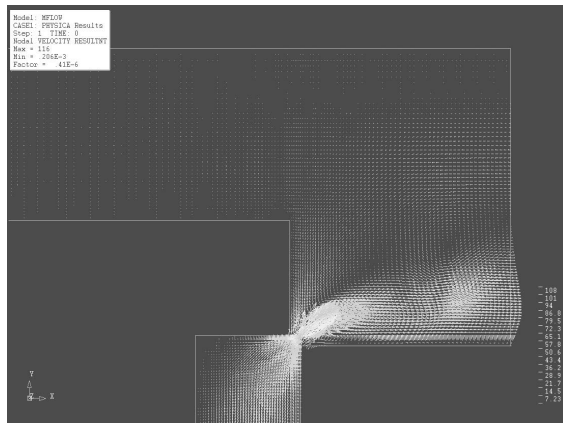


Fig.15. Outcoming airflow with central electrode higher than side electrode (detail)

Taking into account the indications coming from the simulations, changes in the design of the microactuator were introduced as can be seen in Figure 16 and 17.

## 5. Conclusions

A new pneumatic microfeeder based on contactless distributed manipulation was presented in this paper and its design refined thanks to CFD simulations. Advantages of this new design include a more compact actuator (each is about 300  $\mu$ m<sup>2</sup> rather than 600  $\mu$ m<sup>2</sup> as in the initial design), which better fulfills distributed manipulation's requirements and a simplified, and therefore more economic, fabrication sequence (there is no more need for the springs).

A prototype is being built at the University of Nottingham to test the theoretical results and assess

the effect of size and weight of the microparts to be moved on the handling performance.

The outcome of these further investigations will be reported in due course.

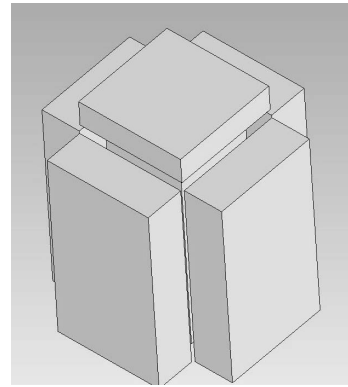


Fig. 16. New microfeeder design

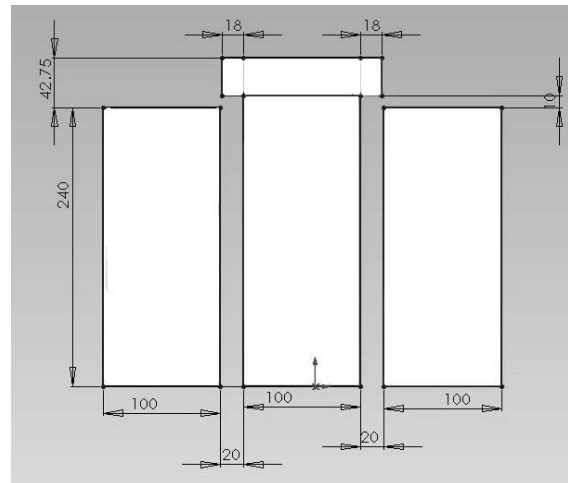


Fig. 17. New microfeeder design cross section

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## References

- [1] Bollinger J., Visionary manufacturing challenges for 2020, National Research Council, 1999, Washington, DC.
- [2] Koelemeijer S. and Jacot J., Cost efficiency assembly of Microsystems, MST-News, January 1999, pp 30-33
- [3] Lambert P., Vandaele V., Delchambre A., Non-contact handling in micro-assembly: state of the art, Proceedings of the International Precision Assembly Seminar IPAS' 2004, Bad Hofgastein, Austria, Feb 11-13, pp 67-76
- [4] Fukuta Y., Yanada M., Ino A., Mita Y., Chapuis Y.A., Konishi S. and Fujita H., Conveyor for pneumatic two-dimensional manipulation realized by arrayed MEMS and its control, Journal of Robotics and Mechatronics, 2004, Volume 16, No. 2, pp 163-170